Investigation of damage to buildings and ground truth verification for satellite data in Kathmandu Valley due to the 2015 Gorkha Earthquake

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ABSTRACT

An earthquake with a magnitude of 7.8 (M_W) occurred at 11:56 NST (local time) on 25 April 2015, in the central part of Nepal (Gorkha). The National Research Institute for Earth Science and Disaster Prevention (NIED) organized a damage survey team and dispatched it to the affected area for several periods following the earthquake (26 May to 3 June, 17 to 24 June and 16 to 21 August) to investigate the damage and collect data. This report outlines the findings of this investigation into various aspects of the earthquake disaster in the Kathmandu valley. We also carried out a first-hand building damage survey in selected areas. The primary purposes of the first and second surveys were to collect timely statistical information on the damage to brick and stone masonry buildings and to confirm the availability of data and their sources for subsequent surveys. The motivation for the thread survey was to obtain ground truth data to calibrate.

Keywords: *Gorkha Nepal Earthquake, Kathmandu, masonry, ground truth*

1. INTRODUCTION

An earthquake with a magnitude of 7.8 (M_w) occurred at 11:56 NST (local time) on 25 April 2015 in the central part of Nepal (Gorkha). The epicenter was east-southeast of Lamjung, 77 km southwest of Kathmandu, at 28.15°N, 84.71°E, and at a depth of 15 km (USGS). According to Nepal Police statistics, the number of deaths, as of 22 June, was 8,660 with 21,952 injured in the main shock and 172 deaths with 3,470 injured in the aftershocks. It was also reported that more than 5 million buildings were damaged, with about half of them experiencing collapse. This earthquake is officially referred to as the 2015 Gorkha Nepal earthquake because the hypocenter was located in the Gorkha region.
A major aftershock with a moment magnitude of 7.3 (M_w) occurred at 12:51 NST on 12 May 2015. The epicenter was 75 km northeast of Kathmandu, near the Chinese border, at 27.82°N, 86.08°E, and at a depth of 19 km (USGS).
The National Research Institute for Earth Science and Disaster Prevention (NIED) organized a damage survey team and dispatched it to the affected area for three periods following the earthquake (26 May to 3 June, 17 to 24 June and 16 to 21 August) to investigate the damage and collect information and data. This report outlines the findings of this investigation into various aspects of the earthquake disaster in the Kathmandu valley (**Figure 1**) and compares vulnerability analyses for "The study on earthquake disaster mitigation in the Kathmandu Valley (JICA, 2002)".

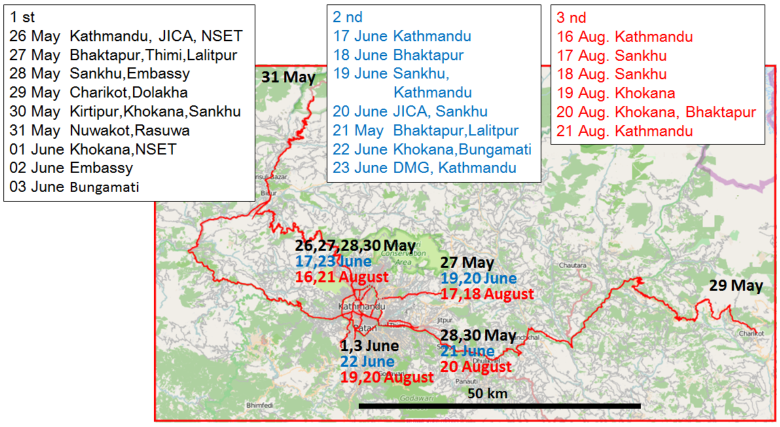

Figure 1: Survey Roots (OpenStreetMap https://www.openstreetmap.org/)

2. SEISMO-TECTONICS AND EARTHQUAKE GROUND MOTION

2.1 The Earthquake as Recorded in Kanti Path (KATNP), central Kathmandu

The strong-motion data set from the USGS Center for Engineering Strong Motion Data (CESMD: http://strongmotioncenter.org/cgi-bin/CESMD/iqr1.pl) includes stations from Nepal that continued to function during the main shock and several subsequent strong aftershocks of the 2015 earthquake series.

Figure 2.1 shows the three components of acceleration and velocity recorded by the CESMD station at the US Embassy in Kathmandu, which recorded the M_w 7.8 main shock (06:11:26 UTC, 28.15°N 84.71°E, 15.0 km deep). **Figure 2.2** shows the three components of the tripartite response spectrum of the main shock and aftershocks. The dominant periods in the Fourier spectra were approximately in the range of 4 to 5 s for magnitude 7 class events. However, for magnitude 5 class events, the dominant periods of the Fourier spectra were about 0.5 s. The response spectrum of the pseudo velocity exceeds the 400 cm/s level of the response spectra in the case of the main shock.

In **Figure 2.1,** the vertical velocity motion waveform has two pulse-like ground motions. The main parts of the velocity waveform can be seen centered at two points: 45.08 and 53.07 s. The difference between the rupture start time and arrival time for the S-wave is 8 s. The dominant period of the body wave is about 4 s.

These sizes can be estimated for each strong motion generation area (SMGA) by direct interpretation of body waves.

The method followed is shown below;

$$R = T_p \times V_r \tag{1}$$

$$V_r = 0.72\ V_s \tag{2}$$

where R: Circular strong motion generation area
T_p: Pulse period
V_r: Rupture velocity
V_s: Share-wave velocity

Thus, two SMGA might exist near the city of Kathmandu.

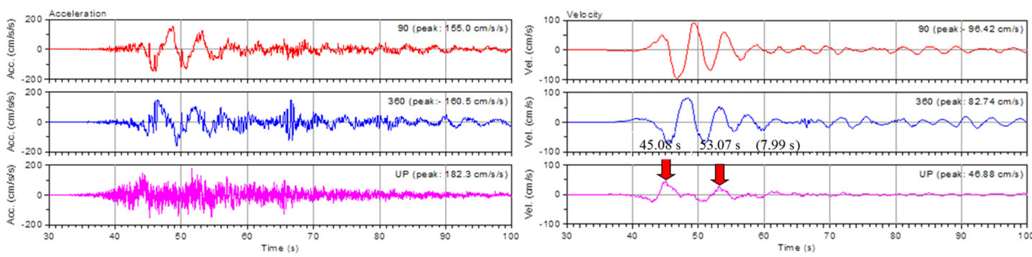

Figure 2.1: Acceleration (left) and Velocity (light) Record of M_w 7.8 main shock

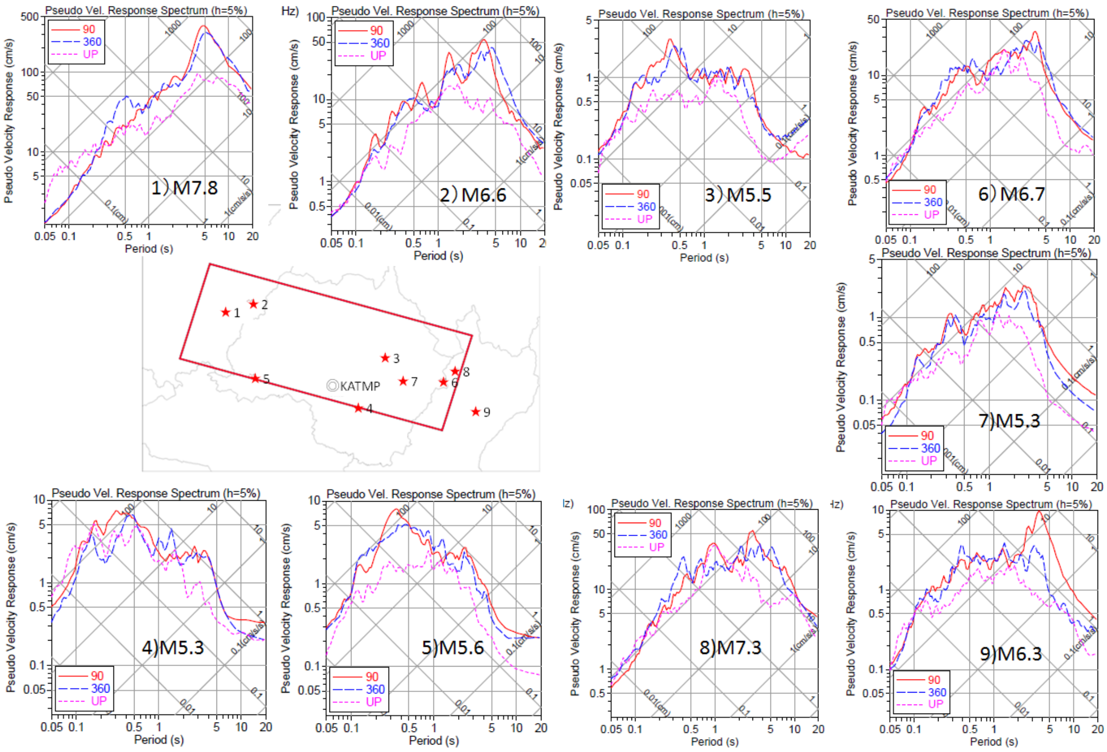

Figure 2.2: Response Spectrum of main shock and Aftershocks.

3. DYNASTIES, HISTORICAL PALACES AND BUILDINGS IN SANKHU

During the Malla dynasties, prior to 1768, there were three kings in the Kathmandu valley. Their palaces were in Kathmandu, Bhaktapur, and Lalitpur/ Patan.

3.1 Bhaktapur

"*Bhakta*" means Devotee in Sanskrit, and pur means city. Thus, "*Bhaktapur*" is the city of devotees. The central areas of these palaces are referred to as "*Durbar Squares*". Bhaktapur's Durbar Square is a conglomeration of pagodas, and during the earthquake series, many Sikhara style temples in Bhaktapur's Durbar Square were severely damaged (**Figure 3.1**).

Figure 3.1: Bhaktapur before / after the earthquake (Photo. by T. Ohsumi), before / after the 1934 earthquake in Bhaktapur (Courtesy of MoHA)

3.2 Lalitpur/ Patan

The Patan Royal Palace complex (Patan in Sanskrit, or "*Yela*" in Newari) is found in the city of Lalitpur, which means the city of beauty. The Patan palace was renovated in 2013 with assistance from the Kathmandu Valley Preservation Trust (KVPT) and the Sumitomo Foundation.
Thus, the palace had only partial damage during the earthquake at the top of structural parts of the buildings (Gajur and Baymvah) (**Figure 3.2**).

Figure 3.2: In Patan, after the earthquake, this place (*a*) had partial damage at top of structure parts (Gajur and Baymvah) (*b*) (Photo. by T. Ohsumi).

3.3 Kathmandu

The old palace structures in Kathmandu's Durbar Square, which had not undergone renovations, had severe damage during the earthquakes (**Figure 3.3**). In the photo on the left, the white structure is about 150 years old, built during the Rana Dynasty. In the photo on the right side, the four-tiered brown temple is about 300 years old, constructed during the Gorkha Dynasty.

After the earthquake

Before the earthquake

Figure 3.3: Kathmandu Durbar Square after the earthquake (*a*), before the earthquake (*b*) (Photo. by T. Ohsumi)

3.4 Sankhu

Houses damaged by the earthquake have been demolished with the support of Canadian Forces relief operations in Sankhu. Heavy equipment was brought for this purpose from Canada. In general, RC buildings were partially damaged, whereas masonry buildings were severely damaged.
The difference in damage as a result of building type was remarkable. Damage in Sankhu was extensive. Brick and cement mortar houses without RC columns experienced a lot of damage. In contrast, the damage to RC structures – particularly those erected in recent years – was generally minor. These structures were mainly five

to six story buildings. In contrast, many of the non-engineered masonry structures that experienced complete collapse or partial damage were two to four story buildings in Sankhu (**Figure 3.4:**left). Damage in non-engineered masonry structures was initiated by vertical cracks in the corners of the buildings (**Figure 3.4:***a*), which contained no RC columns (**Figure 3.4:***b*). The outer wall structures of such buildings was generally burned brick with cement mortar joints to withstand rain. In several cases, the inner walls of buildings are adobe bricks with mud mortar.

Figure 3.4: The damage to RC structures was generally minor.These structures were mainly five to six story buildings. Many of the non-engineered masonry structures that experienced complete collapse or partial damage were two to four story buildings in Sankhu (left). Damage in non-engineered masonry structures was initiated by vertical cracks in the corners of the buildings (*a*), which contained no RC columns (*b*).
(Photo. by T. Ohsumi)

4. LANDSLIDES

A numerous number of huge slope failures which occurred in the mountainous area buried villages and valleys, and resulted in the loss of many lives. We visited a landslide zone in Ramche, and it is located in the northwest of Kathmandu city in a mountainous area. Many of fallen rocks were on the roads, also we encountered a bus that hit by falling rocks (**Figure 4.1**). Thick talus is deposited in the landslide area in Ramche, in Rasuwa district (**Figure 4.2**). The town is located at an altitude of 2,068 m. There are houses that had been caught in a landslide, but the damage was limited. However, the whole scope of the slope failures is not clear at the present time, because any detailed and total survey in the mountainous area has not been carried out. Thus, causalities will in-crease as they are found.

Figure 4.1: Bus was hit in falling rocks in Dhikure,on Baglung Rajmara High way. (Photo. by T. Ohsumi)

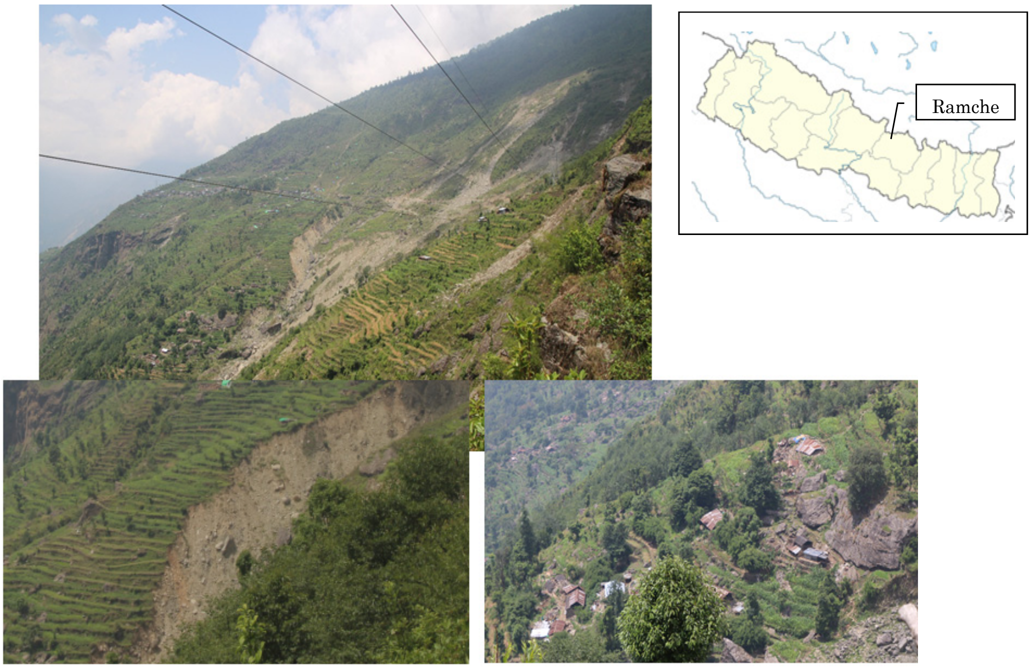

Figure 4.2: Thick talus is deposited in the landslide area in Ramche.
(Photo. by T. Ohsumi)

5. SUBURBANS AND RURAL AREAS

The number of casualties was concentrated to the northeast of the Kathmandu Sindhupalchowk district. We visited Charikot, in the Bhimeshwar Municipality, roughly 50 km east of Dhulikhel. The town is located at an altitude of 1,554 m. The name of the district Dolakha came from Dolakha Town, which is situated northeast of the capital Charikot. These areas had many casualties. According to the locals, the large aftershock felt stronger than the main shock. This is understandable as the aftershock's hypocenter is located just below this area. Many houses collapsed in the aftershock.
Urban and rural housing is significantly different. In the suburban and rural areas where there are many stone houses, a lot of damage occurred. The collapse of heavy stones used in house construction, resulted directly in deaths and property destruction.
In Dolakha district, adobe style houses collapsed. Primarily, adobe houses collapsed as a result of cracks in the gables and corner foundations as a result of ground motion. Many adobe style houses were broken at their gables. Stone houses could also collapse as a result of delamination (**Figure 5**).

Figure 5: Adobe style houses (*left*) and Stone style house (*right*) in Charikot, (Photo. by T. Ohsumi)

6. DISCUSSION

According to Nepal Police statistics as of 22 June 2015, the number of deaths was 8,660 and injuries were 21,952 for the main shock. A total of 172 deaths and 3,470 injuries were associated with the aftershocks. It was also reported that more than 5 million buildings and houses were damaged – and about half of those collapsed; that number is now increasing (**Figure 6**).

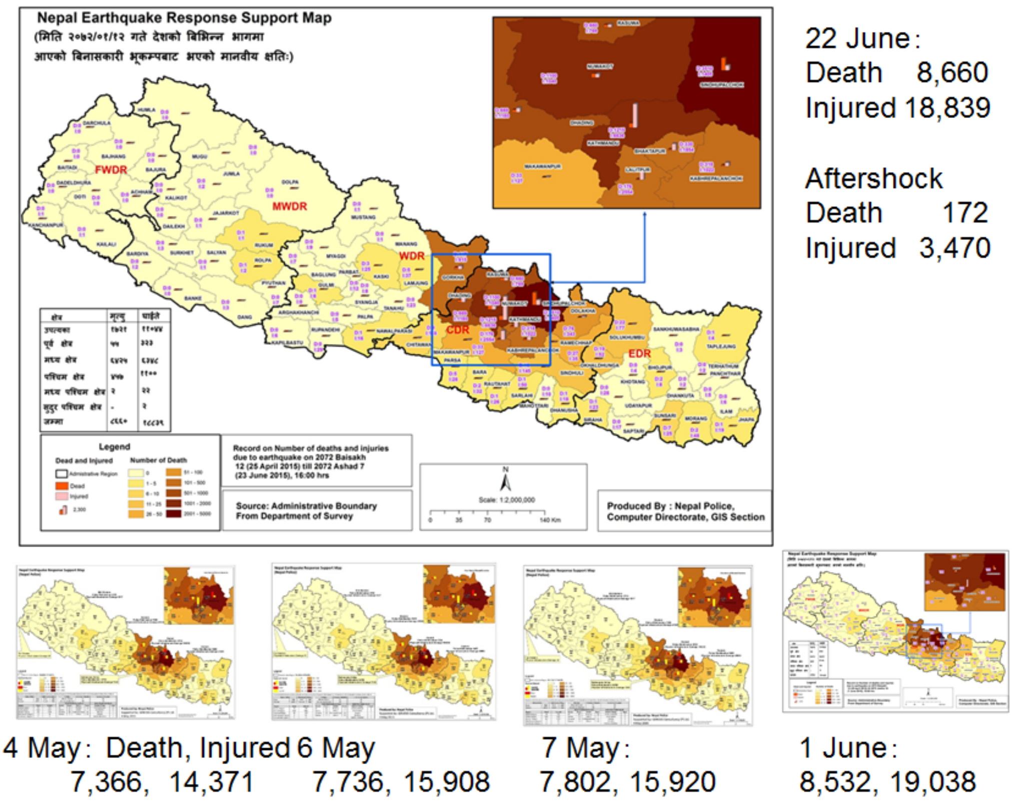

Figure 6: Casualties and injured people by Nepal Police.

Why did this area have concentrated casualties?

First, the dominant rural housing style in the area consists mainly of stone masonry. The collapse of heavy stone buildings killed many. The damage to houses in the mountainous region was typically concentrated in non-engineered structures. In rural areas, unreinforced masonry, sourced from regionally available materials, was the main construction material. Regardless of the masonry material used, serious damage occurred with houses as a result of masonry cemented with mud mortar. This housing construction method also exists in urban areas, primarily for constructions undertaken more than 30 years ago. In the rural areas, this type of housing is still the most popular method of housing construction. Thus, the retrofitting of low-cost earthquake-damaged housing without the consideration of engineering standards is a key issue.

Second, this earthquake involved major high-frequency (1 Hz) seismic energy that can be observed in the earthquake waveforms (Yagi and Okuwaki (2015)). The area is north of the Kathmandu Valley and located near the North Bagmati scenario earthquake model.

The major high-frequency (1 Hz) seismic radiation area was used for the hybrid back-projection analysis of Yagi and Okuwaki (2015). The area is north of Kathmandu Valley, in the vicinity of the North Bagmati scenario earthquake model. This high-frequency seismic radiation caused much of the damage to buildings in the Kathmandu Valley.

7. CONCLUSION

1) Although RC buildings were partially damaged, the difference in damage between buildings with and without RC appears remarkable. Brick and cement mortar houses without RC columns generally had a lot of damage. Structures having no RC columns in the corners generally experienced vertical cracking in the brick masonry walls.
2) The casualties resulting from the earthquake were concentrated in the northeast of Kathmandu in the Sindhupalchok district. Many houses here collapsed in the aftershocks. The casualties were compounded by significant differences in urban and rural housing. In suburban and rural areas, there are many stone houses that were badly damaged. The collapse of heavy stones used in house construction took many lives.
3) The three royal palace complexes in the Kathmandu valley (Kathmandu, Bhaktapur, and Lalitpur / Patan) had undergone significantly different renovation works over the last few decades (although not for the historic structures within the old royal palaces). This enables a means to assess how particular renovations can strengthen historical structures.
4) In rural areas, stone masonry is used as a current building technique. Retrofitting such low-cost non-engineered housing is a key issue.
5) The dominant periods observed in the Fourier spectra of magnitude 7 class events are approximately 4 to 5 s. However, for magnitude 5 class events, the dominant periods are much shorter 0.5 s. These differences in shaking periods / frequencies can have a significant effect on the resulting damage.
7) The major high-frequency (1 Hz) seismic radiation caused much of the damage to buildings and housing on the north side of the Kathmandu Valley.

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